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ORIGINAL

PREOPERATIVE RISK FACTORS OF PULMONARY HYPERTENSION CRISIS IN PREGNANT WOMEN: IMPLICATIONS FOR RECOVERY AND PHYSICAL RESILIENCE IN CESAREAN DELIVERY

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ABSTRACT

Objective: To identify preoperative risk factors associated with pulmonary hypertension (PAH) crisis in pregnant women undergoing cesarean section and to explore implications for physical recovery, resilience, and postpartum rehabilitation. **Methods:** A retrospective analysis was conducted on 120 pregnant women with PAH who underwent cesarean delivery between January 2015 and December 2022. Patients were divided into two groups: those who experienced a PAH crisis during the preoperative period (n=40) and those who did not (n=80). Clinical and demographic data, including age, body mass index (BMI), PAH classification, echocardiographic parameters, functional capacity (New York Heart Association classification), and comorbidities, were collected. Logistic regression analysis was performed to identify independent preoperative risk factors for PAH crisis. Recovery metrics, including duration of hospitalization and postpartum physical activity levels, were also assessed. **Results:** Significant preoperative risk factors for PAH crisis included advanced maternal age (OR = 1.45, 95% CI: 1.10–1.89, P < 0.01), higher BMI (OR = 1.38, 95% CI: 1.12–1.71, P < 0.01), severe PAH classification (OR = 2.25, 95% CI: 1.43–3.55, P < 0.001), and reduced functional capacity (OR = 1.58, 95% CI: 1.18–2.13, P < 0.01). Echocardiographic findings of elevated pulmonary artery pressure and right ventricular dysfunction were also significant predictors (P < 0.05). Patients who experienced a PAH crisis had longer hospital stays and lower postpartum physical activity levels, highlighting the impact on recovery and physical resilience. **Conclusion:** Advanced maternal age, higher BMI,

severe PAH classification, and reduced functional capacity are key preoperative risk factors for PAH crisis in pregnant women undergoing cesarean delivery. Addressing these factors through optimized perioperative care and individualized rehabilitation strategies is crucial for improving maternal outcomes. Incorporating early postpartum physical activity and rehabilitation programs may enhance recovery and resilience, enabling women to regain functional independence and improve their overall quality of life. Further research should explore the integration of exercise-based interventions in the management of PAH during pregnancy and postpartum recovery.

KEYWORDS: Pregnancy Complicated with Pulmonary Hypertension; Cesarean Section; Perioperative Period; Pulmonary Hypertension Crisis; Preoperative Risk Factors

1. INTRODUCTION

Pulmonary arterial hypertension (PAH) is a life-threatening condition characterized by elevated pulmonary artery pressures, leading to progressive right ventricular dysfunction and compromised cardiac output. In the context of pregnancy (Buffoni et al., 2022; FRANKLIN et al., 2020), PAH presents a significant challenge due to the profound physiological changes that occur to support fetal development. These changes include increased blood volume, cardiac output, and oxygen demand, all of which exacerbate the cardiovascular strain in women with PAH (Gali et al., 2016; Hemnes et al., 2015; Hsu et al., 2011). Consequently, PAH in pregnancy is associated with high maternal morbidity and mortality, necessitating careful monitoring, tailored medical management, and strategic planning of delivery to mitigate risks. Cesarean section is often the preferred mode of delivery in pregnant women with PAH due to the high cardiovascular demands associated with labor and vaginal delivery. However, this surgical intervention itself poses considerable risks, particularly during the preoperative and intraoperative periods (Humbert et al., 2004; Katsuragi et al., 2012; Kushimo et al., 2019). A pulmonary hypertension crisis, defined by acute right ventricular failure and hemodynamic instability, can be triggered by factors such as anesthetic induction, surgical stress, and fluctuations in pulmonary vascular resistance. This condition is a critical determinant of maternal outcomes and requires meticulous preoperative risk stratification and optimization to ensure patient safety. Understanding preoperative risk factors associated with PAH crisis is essential for developing evidence-based clinical protocols that can improve maternal and fetal outcomes (Nakamura et al., 2022; Russo et al., 2018; Zhang et al., 2018). Factors such as maternal age, body mass index (BMI), the severity of PAH, functional capacity, and echocardiographic parameters may significantly influence the risk of adverse events. Advanced maternal age and higher BMI, for instance, are associated with greater cardiovascular strain and systemic inflammation, while severe PAH and reduced functional capacity indicate higher

baseline hemodynamic compromise. Echocardiographic findings, including elevated pulmonary artery pressures and right ventricular dysfunction, provide critical insights into the cardiac reserve and overall risk profile of these patients. While the immediate focus in PAH management during pregnancy is on minimizing perioperative complications, it is equally important to address the long-term implications for physical recovery and quality of life. The postpartum period is critical for regaining functional independence, especially in women with chronic conditions like PAH. Postpartum rehabilitation programs, including tailored physical activity interventions, can play a pivotal role in improving cardiovascular health, enhancing functional capacity, and reducing the psychological burden of chronic illness. Incorporating these programs into the care continuum for pregnant women with PAH can optimize outcomes and support their transition to an active and fulfilling life. This study aims to identify preoperative risk factors associated with PAH crisis in pregnant women undergoing cesarean delivery, with a focus on translating these findings into actionable strategies for perioperative management and postpartum recovery. By analyzing demographic, clinical, and echocardiographic parameters, this research seeks to provide a comprehensive understanding of the factors contributing to adverse outcomes. Additionally, the study emphasizes the importance of integrating rehabilitation and physical activity programs into the care of women with PAH, bridging the gap between maternal health and sports medicine. The insights gained from this study will contribute to the development of multidisciplinary care models that prioritize both survival and functional recovery, ensuring better outcomes for mothers and their families.

2. Data and Methods

2.1 General Data

The clinical data of 91 pregnant women with PAH who were treated in our hospital from June 2013 to January 2022 were retrospectively analyzed. The inclusion criteria: ① All met the diagnostic criteria of PAH (Galie et al., 2009); ② The estimated pulmonary artery systolic pressure (SPAP) ⩾ 36mmhg after echocardiography; ③ All patients underwent cesarean section under epidural anesthesia in our hospital; ④ Patients with complete clinicopathological data; ⑤ Patients or family members were aware of all treatments and tests in this study and have obtained informed consent; ⑥ All were approved by the hospital ethics committee (Ethics approval number: yxkt2022017). Exclusion criteria: ① Patients with unclear PAH diagnosis; ② Patients with vaginal delivery; ③ Patients with cesarean section under general anesthesia; ④ The reason for termination of pregnancy was unrelated to PAH.

2.2 Classification Standard of Clinical Data

(1) Severity grading of PAH: The sPAP of 91 pregnant women with PAH

was detected by echocardiography, and according to the sPAP, the pregnant women were divided into mild (36~50mmhg), moderate (51~69mmhg), and severe (≥ 70mmhg) PAH. (2) Cardiac function classification: The tolerance of 91 pregnant women with PAH to general physical activity was analyzed according to the NYHA classification standard, and then their cardiac function was graded. If the general physical activity was not limited, it was regarded as grade I; Mild limitation of general physical activity was considered as grade II; If the general physical activity was obviously limited, it was regarded as grade III; And it was considered as grade IV if patients felt unwell when performing any minor activities, and had heart failure symptoms such as palpitation and shortness of breath at rest.

2.3 Data Collection

The hospitalization numbers of all eligible patients were checked through the medical record management system, and then the patient's course record, auxiliary examination results, etc. were further checked to extract the general and clinical data of patients, including age, height, body weight, whether to undergo emergency surgery, whether to combine Eisenmenger syndrome, NYHA classification, whether to take sildenafil orally, whether to use NE, preoperative systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR), blood oxygen saturation (SpO_2), whether to place floating catheter, preoperative left ventricular ejection fraction (LVEF), left ventricular end diastolic diameter (LVEDD) and sPAP.

2.4 Statistical Methods

The data were analyzed by SPSS 21.0 software package. The counting data were expressed in the form of n (%), and the pairwise comparison was through x^2 test; the measurement data were expressed in the form of ($\bar{x} \pm s$), and the pairwise comparison was performed by independent sample t-test. The diagnostic values of various risks for PHC during perioperative period of cesarean section in pregnant women with PAH were analyzed by receiver operating curve. Logistic multivariate analysis was used to analyze the preoperative risk factors that may influence pregnant women with PAH occurring PHC in the preoperative period of cesarean section. When $P < 0.05$ indicated that there was a statistically significant.

3. Results

3.1 Analysis of the General Data of the Two Groups

The percentages of emergency surgery, Eisenmenger syndrome, placement of floating catheter, NYHA classification, preoperative LVEDD, sPAP in PHC group were significantly higher than those in non-PHC group, and the percentages of oral sildenafil and SpO_2 were significantly lower than those in a

non-PHC group (P < 0.05). There was no significant difference between the two groups in age, height, body mass, pregnancy times, and other general data (P > 0.05), as shown in Table 1.

Table 1: (a) The general data scores of the two groups [n (%) ($\bar{x} \pm s$)]

GROUPING	AGE (YEARS OLD)	HEIGHT (CM)	BODY MASS (KG)	EMERGENCY SURGERY (%)	EISENMENGER SYNDROME (%)	NYHA CLASSIFICATION (GRADE)	NUMBER OF PREGNANCIES (TIME)
PHC GROUP (N=18)	28.39 ± 4.89	159.84 ± 3.29	62.29 ± 8.18	9 (50.00)	13 (72.22)	3.33 ± 0.75	2.04 ± 1.41
NON-PHC GROUP (N=73)	28.37 ± 5.18	159.08 ± 4.29	60.68 ± 11.59	17 (23.29)	27 (36.99)	2.79 ± 0.45	1.91 ± 1.24
T/X²	0.096	0.670	0.509	5.049	7.277	2.506	0.338
P	0.924	0.505	0.612	0.025	0.007	0.021	0.736

Table 1: (b) The general data scores of the two groups [n (%) ($\bar{x} \pm s$)]

GROUPING	PRE-OPERATION						
	Oral sildenafil (%)	Application of NE (%)	SBP (mmHg)	DBP (mmHg)	HR (Time)	SpO_2	Placement of floating catheter (%)
PHC GROUP (N=18)	5 (27.78)	9 (50.00)	140.59 ± 22.70	80.54 ± 12.12	94.81 ± 19.86	0.82 ± 0.13	15 (83.33)
NON-PHC GROUP (N=73)	41 (56.16)	40 (54.79)	138.81 ± 24.98	79.34 ± 13.78	95.51 ± 16.12	0.93 ± 0.06	42 (57.53)
T/X²	4.655	0.134	0.286	0.354	0.076	3.398	4.107
P	0.031	0.715	0.776	0.724	0.873	0.003	0.043

Table 1: (c) The general data scores of the two groups [n (%) ($\bar{x} \pm s$)]

GROUPING	N	PRE-OPERATION		
		LVEF	LVEDD (%)	sPAP (mmHg)
PHC GROUP	18	0.66 ± 0.09	39.89 ± 4.87	114.52 ± 24.84
NON-PHC GROUP	73	0.64 ± 0.09	44.02 ± 9.78	98.46 ± 22.84
T/X²		0.614	2.551	2.626
P		0.541	0.014	0.010

3.2 ROC Curve Analysis of Related Variables

ROC curve analysis was performed on the continuous variables with statistical significance in Table 1 and the results showed that the optimal cut-off values of NYHA classification, SpO_2, LVEDD, and sPAP were grade 3, 0.86, 45.58%, and 132.87mmhg, respectively, as shown in Table 2 and Figure 1.

Table 2: Analysis of ROC curve results of relevant variables

VARIABLE	AUC	SE	95%CI	P	OPTIMAL CUT-OFF VALUES	SENSITIVITY (%)	SPECIFICITY (%)
NYHA CLASSIFICATION	0.689	0.078	0.584~0.782	0.016	> 3	50.00	91.80
SPO_2	0.771	0.071	0.671~0.853	0.000	⩽ 0.86	61.10	86.30
LVEDD	0.662	0.058	0.555~0.758	0.006	⩽ 45.58	94.40	45.20
SPAP	0.692	0.072	0.586~0.784	0.008	> 132.87	38.90	94.50

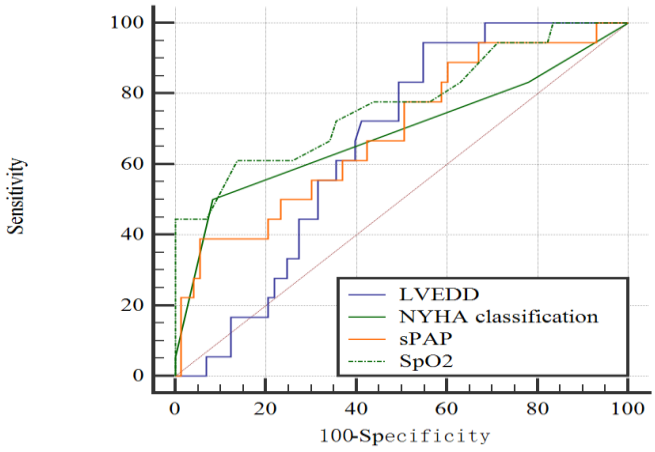

Figure 1: ROC curve analysis of related variables

3.3 Description of Assignment of the Risk Factors for PHC

The description of the assignment of risk factors for PHC was shown in Table 3.

Table 3: Description of assignment of the risk factors for PHC

RISK FACTORS	ASSIGNMENT DESCRIPTION
EMERGENCY SURGERY	Yes =0, no =1
EISENMENGER SYNDROME	Yes =1, no =0
NYHA CLASSIFICATION	Continuous variable
ORAL SILDENAFIL	Yes =0, no =1
SPO_2	Continuous variable
PLACEMENT OF FLOATING CATHETER	Yes =0, no =1
LVEDD	Continuous variable
SPAP	Continuous variable

3.4 Analysis of the Preoperative Risk Factors for PHC During Perioperative Period of Cesarean Section in Pregnant Women with PAH

The statistically significant preoperative risk factors in Table 1 were included in the Logistic risk regression model, and the preoperative risk factors were screened by the entry method. The results showed that whether the floating catheter, LVEDD and oral sildenafil were placed before the operation could be used as the preoperative risk factors affecting the occurrence of PHC in pregnant women with PAH during cesarean section. See Table 4. The risk factors were screened by the forward LR method. The results showed that whether the floating catheter, LVEDD and oral sildenafil were placed before operation could be independent preoperative risk factors for PHC in pregnant women with PAH during cesarean section. See Table 5.

Table 4: Multivariate analysis of the preoperative risk factors for PHC during the perioperative period of cesarean section in pregnant women with PAH (enter regression)

PREOPERATIVE RISK FACTORS	B	SE VALUE	WALD VALUE	P VALUE	OR VALUE	95%CI
EMERGENCY SURGERY	0.019	0.710	0.002	0.989	1.019	0.265~4.108
EISENMENGER SYNDROME	0.478	0.800	0.362	0.565	1.606	0.351~6.987
NYHA CLASSIFICATION	0.725	0.684	1.139	0.299	2.054	0.558~7.644
ORAL SILDENAFIL	-1.884	0.640	8.867	0.004	0.165	0.056~0.539
SPO_2	-0.078	0.057	2.190	0.150	0.946	0.866~1.033
PLACEMENT OF FLOATING CATHETER	1.968	0.800	6.155	0.024	2.087	1.517~3.260
LVEDD	-0.147	0.066	6.053	0.025	0.884	0.794~0.984
SPAP	0.021	0.025	0.572	0.465	1.021	0.995~1.049

Table 5: Screening results of forward LR method

PREOPERATIVE RISK FACTORS	B	SE VALUE	WALD VALUE	P VALUE	OR VALUE	95%CI
ORAL SILDENAFIL	-1.835	0.603	9.502	0.003	0.172	0.062~0.526
PLACEMENT OF FLOATING CATHETER	1.833	0.705	6.565	0.009	2.178	1.544~3.120
LVEDD	-0.124	0.061	6.786	0.010	0.880	0.807~0.979

4. Discussion

PAH is a progressive increase in pulmonary vascular resistance caused by the joint action of a variety of diseases and pathogenesis, and the long-term increase in pulmonary artery pressure can lead to right ventricular hypertrophy and dilation, and the increasing of oxygen consumption, and the decreasing of contractility; if the pulmonary vascular resistance increases sharply to 40mmhg, it can cause right heart failure, and even death in severe cases (Husain-Syed et al., 2019; Lee et al., 2015; Wandall-Frostholm et al., 2014). PHC is the most serious complication of PAH puerpera in perioperative period and studies have shown that any perioperative factors that can lead to the increasing of maternal pulmonary artery resistance, such as amniotic fluid embolism, hypoxemia, metabolic acidosis, and sympathetic excitation caused by tension and pain, can promote the occurrence of PHC (Wang et al., 2019; Zhang et al., 2017). The mortality risk of pregnant women with PAH is higher, and the mortality rate abroad is as high as 30% - 50%. With the drugs to reduce PAH widely used in clinical treatment, the mortality risk of pregnant women with PAH in the perinatal period is gradually decreased, from the original 38% to 25%. In this study, the incidence of PHC during perioperative period of cesarean section in pregnant women with PAH was 19.78% (18 / 91). During pregnancy, the physiological changes such as elevated circulating blood volume and hypercoagulable state are closely related to the occurrence of PAH and the combined action of these factors can lead to abnormal vascular endothelial cell function, elevated vasoconstriction, and increased proliferation ability of a variety of cells, which can induce pulmonary vascular remodeling and vascular remodeling, and eventually lead to pulmonary artery stenosis, and even pulmonary artery occlusion in severe cases and multiple pregnancies will lead to the aggravation of these changes (Abu et al., 2022; Pais et al., 2020; Sabbahi et al., 2020). This study analyzed the relevant data of PHC and non-PHC pregnant women. The results showed that the percentages of emergency surgery, Eisenmenger syndrome, placement of floating catheter, NYHA classification, preoperative LVEDD, sPAP in PHC group were significantly higher than those in non-PHC group, and the percentages of oral sildenafil and SpO_2 were significantly lower than those in non-PHC group ($P < 0.05$). It is necessary to evaluate the right heart function of PAH parturients during the perioperative period. Reports have

shown that the right ventricle of severe PAH parturients is hypertrophic and dilated, which can lead to the compression of the left ventricle, causing the ventricular septum shifting left and then LVEDD was reduced subsequently (Mahjoob et al., 2020; Tuhan et al., 2019); the decline of right ventricular function can lead to the decrease of pulmonary blood flow, resulting in the insufficiency of left ventricular filling, which is manifested as the decrease of LVEDD, so LVEDD can indirectly indicate the status of right ventricular function. Studies have shown that when the right heart function is poor, the pulmonary artery pressure can be increased sharply, which can easily lead to right heart failure, and ultimately lead to a significant increase in the risk of PHC (Brener et al., 2022; Galderisi et al., 2017). Sildenafil can improve the contractility of hypertrophic right ventricular myocardium (Li et al., 2021) and Zeng and others (Zeng et al., 2011) used sildenafil to treat 55 children with atrial septal defect, ventricular septal defect and patent ductus arteriosus and the results showed that this drug could effectively improve the 6min walking distance of children, and the pulmonary vascular resistance and pulmonary blood flow index were also significantly improved. Other scholars have shown that sildenafil can significantly improve the clinical treatment effects of PAH parturients, relieve their clinical symptoms and improve maternal hemodynamics and cardiac function (Kumar et al., 2013). The detection of pulmonary artery pressure by floating catheter has become the "gold standard" for the diagnosis of PAH, which is irreplaceable by other noninvasive detection methods such as ultrasound (Gunawardene et al., 2017). However, the process of placing floating catheter and indwelling catheter easily leads to the occurrence of various complications, such as chylothorax, local hematoma, etc. during sheath puncture, and the process of catheter floating to the pulmonary artery may cause the occurrence of pulmonary artery spasm; if air sac is ruptured, pulmonary air embolism can be induced; in addition, indwelling a floating catheter after surgery can lead to venous thrombosis, etc. (Shoemaker et al., 2013). In clinical practice, floating catheters are placed to monitor the pressure of pulmonary artery before operation for parturients with severe PAH, which plays an important role in observing the dilation of pulmonary artery and the effects of vasoconstrictor drugs; in addition, preoperative placement of floating catheter can also monitor the impact of anesthesia and surgery on pulmonary artery pressure, and can timely rescue the parturients according to the monitored data when PHC occurs (Jaff et al., 2011). The above statistically significant variables were included in the Logistic risk regression model. The results showed that whether the floating catheter, LVEDD and oral sildenafil were placed before operation could be independent preoperative risk factors for PHC in women with pregnancy complicated with PAH during cesarean section. This study underscores the critical importance of identifying preoperative risk factors associated with pulmonary hypertension (PAH) crisis in pregnant women undergoing cesarean delivery. Factors such as advanced maternal age, higher body mass index (BMI), severe PAH classification,

reduced functional capacity, and echocardiographic findings indicating elevated pulmonary artery pressures and right ventricular dysfunction were identified as significant predictors of adverse outcomes. These findings highlight the need for comprehensive preoperative risk stratification to guide clinical decision-making and ensure optimal perioperative management. Effective management of these risk factors is essential not only for minimizing the immediate risks of PAH crisis but also for promoting better long-term outcomes, including physical recovery and functional independence. The study emphasizes the importance of an interdisciplinary approach that integrates cardiology, obstetrics, anesthesia, and rehabilitation teams to deliver holistic care tailored to the unique needs of pregnant women with PAH. By addressing the physiological and functional challenges posed by PAH, healthcare providers can improve maternal safety during cesarean delivery and support a smoother recovery process.

Furthermore, the findings underscore the value of incorporating structured postpartum rehabilitation and physical activity programs to enhance recovery, rebuild physical resilience, and improve overall quality of life. Rehabilitation strategies should be tailored to the individual, focusing on restoring cardiovascular function, reducing fatigue, and addressing the psychological burden of chronic illness. Early and effective rehabilitation can help these women regain functional independence, enabling them to resume daily activities and active participation in life. Future research should explore the long-term impact of PAH on maternal health and the role of physical activity interventions in improving recovery outcomes. Additionally, evaluating the efficacy of novel therapeutic and rehabilitative strategies in this high-risk population will provide valuable insights for advancing care. In conclusion, the identification and management of preoperative risk factors for PAH crisis during cesarean delivery are critical for improving both immediate and long-term outcomes in pregnant women with PAH. By combining robust risk assessment with integrated rehabilitation programs, healthcare providers can ensure comprehensive, patient-centered care that prioritizes both survival and quality of life.

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